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A New Method for Position Location in Random Media

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Abstract

The development of wireless communication techniques has increased, as a consequence, the use of positioning systems. Concerning to this, GSM providers have predicted that position location will be an integrated service in the 3rd generation cellular phones. The techniques that are used by each one of the current positioning systems are well-known; they include time-difference-of-arrival measures, angle-of-arrival measures and power-of-arrival measures. In this paper we propose a new method, which is based on the transmission of several frames with different frequencies in order to determine the transmitter/receiver distance.

1. Introduction

Unlike wired communication systems that are static and easily characterized, radio channels are highly random, time varying and difficult to predict. The propagation path in a wireless communication system can vary in real-time from close range, stationary, line of sight to a heavily obstructed mobile path due to both moving and stationary objects [1]. Needless to say, although wireless communication systems share the radio channel as a common limiting factor, the channel can be extremely random in nature [2] and thus plays a major role in the design of many radio frequency communication systems.

One of the new uses of these systems is to provide accurate user position location (PL) information, and that is the reason why several different position location technologies have been developed in the last few years [3]. As it is well-known, the behavior of electromagnetic waves through random media is modified by several factors that appear in the environment [4]. If we know the limiting factors that restrict the propagation of the waves, the medium will be properly characterized and, as a result, a relationship between the propagation velocity and the frequency of transmission will be defined.

In this work, we propose a new method to determine the distance between the transmitter and the receiver by solving a system of non-linear equations, that depends on the physical model of the medium in which the wave is propagated. In Section 2, the theoretical basis of our method is described. Consequently, a system with a transmitter, a microscopic model of the channel and a receiver is simulated in *MATLAB*. The results are shown in Section 3. Finally, some conclusions are remarked in Section 4.

2. Previous Concepts of the Multi-Frequency Model

The propagation of electromagnetic waves depends on internal factors related to its nature and external factors that are characterized by means of the medium in which the wave is propagated. There are

many developments in this field: some measures of the GPS propagation principles can be found in [5], where reception delays due to atmospheric phenomena are estimated. Concerning to this, the ionospheric delays are considered in [6]. In both cases, the delays not only depend on the medium itself, but also on the signal frequency.

Taking into account these studies, a method which uses a multi-frequency technique, that is, the transmission of several frames with different frequencies, is proposed. Let us consider the general relationship:

$$v_i = g(w_i, k_1, \ldots, k_j) \tag{1}$$

where v_i is the propagation velocity and depends on the frequency, g is some function which must be determined, w_i is the frequency, and $k_1,\ldots,k_j$ are the factors related to the medium of propagation. From Eq. (1), the distance between the transmitter and the receiver can be estimated by using a system of non-linear equations [7]. These equations are obtained regarding these assumptions:

- If we suppose that a frame consisting of n frequencies is transmitted, then n equations like the following ones are obtained:

$$\begin{aligned} v_1 \cdot t_1 &= d \\ &\vdots \\ v_n \cdot t_n &= d \end{aligned} \tag{2}$$

  where $t_1,\ldots,t_n$ are the times of arrival for each frequency and d is the distance between the transmitter and the receiver.

- If the time difference of arrival for the different frequencies is calculated, c_i, then we will have n–1 equations, where the delay between each one of the frequencies is determined:

$$\begin{aligned} t_1 - t_2 &= c_1 \\ &\vdots \\ t_1 - t_n &= c_{n-1} \end{aligned} \tag{3}$$

- Finally, if we know the relationship between the velocities/frequencies, n equations like these ones can be found:

$$\begin{aligned} v_1 &= g(w_1, k_1, \ldots, k_j) \\ &\vdots \\ v_n &= g(w_n, k_1, \ldots, k_j) \end{aligned} \tag{4}$$

Therefore, the distance d, the n propagation velocities, the n times and the factors that represent the medium must be calculated. We have, then, a system with $3n$–1 equations and $2n$+1+j unknown quantities, and, as a consequence, $n = j + 2$.

3. Position Location using the Multi-Frequency Model

In a common way, when the transmitter/receiver distance is found out, the equations system to determine the proper position of an object/person can be obtained as:

$$(X_i - R_x)^2 + (Y_i - R_y)^2 + (Z_i - R_z)^2 = d_i^{\,2} \tag{5}$$

where (R_x, R_y, R_z) is the receiver position, (X_i, Y_i, Z_i) are the n transmitters position, and d_i are the distances to each one of the n transmitters.

The parameters of the model that characterizes the medium can vary when the link conditions change. That is the reason why the positioning system will have to update the model in real-time. Following these requirements, a *MATLAB* simulation to calculate the distance in a satellite-earth link has been made. Considering the Drude-Lorentz's model for the ionosphere [8], we have:

$$k_r - 1 = \frac{w_p^2}{w_0^2 - w^2} \tag{6}$$

where k_r is the real part of the dielectric constant of the medium, w_p is the plasma frequency and w_0 is the natural frequency. If the refractive index is $n = \sqrt{k_r}$, the propagation velocity will be:

$$v = g(w, k_1, k_2) = \frac{c}{n} = \frac{c}{\sqrt{1 + \dfrac{w_p^2}{w_0^2 - w^2}}} \tag{7}$$

When a two-parameter model is used, the equations system will be:

$$\frac{c}{\sqrt{1 + \dfrac{k_1}{k_2 - w_i^2}}} \cdot t_i = d \tag{8}$$

where i = 1,2,3,4. The time differences can be calculated as:

$$\begin{aligned} t_1 - t_2 &= c_1 \\ t_1 - t_3 &= c_2 \\ t_1 - t_4 &= c_3 \end{aligned} \tag{9}$$

We see that the unknown quantities are [t_1, t_2, t_3, t_4, k_1, k_2, d]. As a result, we can deduce that the frames must be sent including four frequencies. We have to point out that we have used the Newton's method to solve the non-linear equations system. That is, the starting equations system is:

$$\begin{matrix} f_1(x_1, x_2, x_3, x_4, x_5) = 0 \\ \cdots \\ f_7(x_1, x_2, x_3, x_4, x_5) = 0 \end{matrix} \quad \Rightarrow \quad \vec{F}(\vec{x}) = \begin{pmatrix} f_1(\vec{x}) \\ \vdots \\ f_7(\vec{x}) \end{pmatrix} = 0 \tag{10}$$

Using the Taylor's expansion of Eq. (10), we obtain:

$$\vec{F}(\vec{x}) \approx \vec{F}(\vec{x}_0) + J(\vec{x}_0) \cdot (\vec{x} - \vec{x}_0) \tag{11}$$

where $J(\vec{x}_0)$ is the Jacobian matrix in the initial point $\vec{x}_0$ = [t_{10}, t_{20}, t_{30}, t_{40}, k_{10}, k_{20}, d_0].

As a consequence, the following conditions must be considered:

1. A vector with some initial values for the variables of the system must be introduced.

2. After that, the Jacobian matrix $J(\vec{x}_{0(t-1)})$ for the current solution vector $\vec{x}_{0(t-1)}$ is calculated. The new solution vector is determined as:

$$\vec{x}_{ot} = \vec{x}_{0(t-1)} - J^{-1}(\vec{x}_{0(t-1)}) \cdot \vec{F}(\vec{x}_{0(t-1)}) \quad (12)$$

where $J^{-1}(\vec{x}_{0(t-1)})$ is the inverse matrix of $J(\vec{x}_{0(t-1)})$.

3. $\vec{x}_{0t}$ is replaced in $\vec{F}(\vec{x})$ and the error value is obtained. The variation of the error is revised to establish whether the solution is correct or not, and, then, if the algorithm is finished.

Table 1 shows the error in the calculation of the distance, for some different examples.

Distance	*500*	*1000*	*5000*
Two-parameter error	1.2 %	0.1 %	0.01 %

Table 1: Variation of the error and distance

4. Conclusion

In this paper we have explained a new method to reach a complete position location service. We have shown in a theoretical way that scattering phenomena can be used to estimate the transmitter/receiver distance in a radio frequency link. Moreover, any electromagnetic communication in which scattering appears could be considered in the same way. Some of the advantages of this system are, on the one hand, that there are no measures in absolute time and, on the other hand, that it is not necessary to synchronize the receiving antennas (see [7]).

As a future work, we propose to combine this method with a power-of-arrival one so as to avoid the wrong distance estimations. Finally, the design of the whole positioning system, hardware and software, will be considered as well.

References

[1] J. B. Anderson, T. S. Rappaport, and S. Yoshida, "Propagation Measurements and Models for Wireless Communication Channels," *IEEE Communications Magazine*, vol. 32, no. 11, pp. 56-62, November 1994.
[2] S. S. Saunders, *Antennas and Propagation for Wireless Communication Systems*. Chichester, United Kingdom: John Wiley & Sons, 1999.
[3] T. S. Rappaport, J. H. Reed, and B. D. Woerner, "Position Location using Wireless Communications on Highways of the Future", *IEEE Communications Magazine*, vol. 34, no. 10, pp. 33-41, October 1996.
[4] S. Ichitsubo *et al.*, "A Statistical Model for Microcellular Multipath Propagation Environment", in *Proc. of the 47th IEEE Vehicular Technology Conference*, Arizona, USA, May 1997, pp. 61-66.
[5] F. S. Solheim, J. Vivekanandan, R. H. Ware, and C. Rocken, "Propagation Delays induced in GPS Signals by Dry Air, Water Vapor, Hydrometeors, and Other Particulates", *Journal of Geophysical Research*, vol. 104, no. D8, pp. 9663-9670, April 1999.
[6] D .A. Imel, "Evaluation of the TOPEX Dual-Frequency Ionosphere Correction", *Journal of Geophysical Research*, vol. 99, no. C12, pp. 24985-24906, December 1994.
[7] F. J. Ferrández Pastor *et al.*, "Método para la determinación de distancias mediante técnica multifrecuencial", in *Proc. of the Conferencia Internacional de Telecomunicaciones y Electrónica (TELEC'2000)*, Santiago de Cuba, Cuba, Julio 2000.
[8] J. R. Reitz, F. J. Milord, R. W. Christy, *Fundamentos de la Teoría Electromagnética*. Mexico D.F., Mexico: Addison-Wesley Iberoamericana, 1986.